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UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH ADMINISTRATION
BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

RLF JWW for WJL

Project Date May 7, 1951 Author Philip C. Johnson

TITLE

HEIGHT OF BROODS AS A FACTOR AFFECTING THE TREATMENT OF STANDING LODGEPOLE PINE TREES INFESTED BY THE MOUNTAIN PINE BEETLE

By Philip C. Johnson, Entomologist

Forest Insect Laboratory
Coeur d'Alene, Idaho

SUBJECT—

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UNITED STATES DEPARTMENT OF AGRICULTURE
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BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE
233 Forestry Bldg., Colo. A & M
Fort Collins, Colorado
June 21, 1951

To: R. L. Furniss, in Charge, Forest Insect Laboratory,
Room 445, U.S. Courthouse, Sixth and Main Streets, Portland 5
From: Noel D. Wygant, Entomologist in Charge

Subject: Report--"Height of Broods as a Factor Affecting the Treatment of Standing Lodgepole Pine Trees Infested by the Mountain Pine Beetle"

A copy of your memorandum of May 24 to Mr. Evenden was received. I wanted each of the men at this station to see the letter before making the reply. None of the men have made any comments and I am afraid that what few comments I may have are unimportant.

The effective height of sprays on the standing trees needs much more extensive study than we have made to date. We believe that heights greater than those reported by us earlier can be obtained by heavier applications of insecticides near the maximum heights obtainable with the solid stream spray. As you know, a solid stream spray fans out near the upper limbs of the maximum height. This results in a rather uniform wetting of the bark and the amount applied is deceiving. In other words, the spray should be held on the point of maximum height for a time sufficient to result in run-down of the spray.

Along with the more accurate determination of the maximum height of effective treatment we also need to study the brood population. It is our impression that the brood is very light in the upper part of the stem and the fact that the spray does not reach within 4 or 5 feet of the last egg gallery may be insignificant.

We have seen so many inconsistencies in mountain pine beetle and Black Hills beetle infestation that we are reluctant to give our opinion as to what constitutes a high hazard stand. In general, the size of the tree seems to be very important. At least the larger trees produce the heaviest broods. More directly may be the bark thickness. The younger trees and the suppressed trees of small diameters have very thin bark, often so thin that the beetle hardly has room to make the egg gallery. On the other hand, we observed the situation on the Wasatch National Forest in which the infestation in the smaller trees in Fish Creek never got into the old, mature stands of large trees in the adjacent Granddaddy Lake basin. Likewise, the virulent outbreak of the Black Hills

beetle in ponderosa pine on the Black Hills and Harney National Forests was confined almost entirely to the dense black jack stands less than 125 years of age. The beetles in this case seemed to prefer the younger dominate trees and the scattered old mature trees.

It is our general impression that the stand, as a whole, becomes susceptible during certain periods rather than individual trees within the stand. To date, we have not been able to tie in these susceptible periods with both precipitation and smaller tree growth. Because we had a great many outbreaks during the decade following 1930, many people got the impression that the outbreaks were tied in with the drought during that period. We also saw many outbreaks during the 1940-1950 decade which was a period of better than average precipitation.

Noel D. Haygood

cc: Beal
Coeur d'Alene
Ogden
Berkeley

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Forest Insect Laboratory
Coeur d'Alene, Idaho

File No. [illegible]
Noted by RLF JMW
WJB
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KHW

May 28, 1951

To: R. L. Furniss, In Charge, Portland Forest Insect Laboratory

From: J. C. Evenden, In Charge, Coeur d'Alene Forest Insect Lab.

Subject: Treating Standing Infested Lodgepole

Thank you for your comments on Mr. Johnson's paper on the treating of standing infested lodgepole pine. We hoped that this paper would bring forth several such comments. Obviously the treatment of standing infested lodgepole cannot be adopted as a standard practice. Perhaps we must go back to the combined practice of felling such trees that cannot be treated to a proper height. Perhaps with the portable power saw we may find that it will be less expensive and more effective to fell all trees for treatment. The difficulty of getting men to treat standing trees properly makes me lean rather heavily to the fell and treat idea. At least we must watch each situation to see that standing treating is effective.

Your question as to how much brood area, if any, can be safely left untreated, is a bad one. Perhaps it would be biologically sound to leave a bit of brood for parasite, predator, and woodpecker food, but how much and when are questions. I do have a definite opinion as to how much untreated brood surface we should be willing to accept on our control operations. My answer is - none. If we point our control efforts to a 100% performance, we may get an acceptable 95%. But if we say we will accept 95%, we will get 85, and so on. We stress 100% when we know that will never be possible. Anyway we are trying.

I am greatly interested in your remarks as to the possibility of hazard rating in lodgepole pine. We are also interested in this phase of lodgepole pine management, but up to the present time there has been nothing but talk. However, on the Kootenai Forest where poles are a very saleable commodity, some action may be taken. On this forest they plan to use a small crew in an attempt to establish cutting priorities of all mature lodgepole pine. I feel that there is a distinct relationship between the vigor of a lodgepole pine stand and its susceptibility to such destructive forces as bark beetles. I have had some correspondence with Mr. Oaks who will be in charge of this work, and have discussed the

problem with him a time or two. In response to his request for criteria that his men might use in establishing these priorities, I wrote him at considerable length, without offering a great deal of help. However, I did try to set up the factors that would need be considered in establishing the vigor of a timber stand. Unfortunately, there are other factors than vigor that will enter into this problem.

The solution of this problem will encounter both ecological and economic considerations. Although different in their scope, they must receive full recognition. Merchantable volumes and accessibility will influence priorities. However, accessibility is the manager's ability to follow an established order of priorities, and should not affect the ratings. Cutting priorities should be based upon stand values and the expected depreciation from these values, over a set period of years.

Yes this does seem far from the subject of brood heights, so I had better stop now, or I will go on and on. If you come this way with Mr. Parker I would like to discuss this problem with you, as I would like your ideas.

Thanks again.

James P. Lounsbury

cc: Dr. Beal
Berkeley
Ogden
Fort Collins

cc: Dr. Ekin
Dempsey
Lyons
Prof. Collins

J. C. Evenden, In Charge, Coeur d'Alene May 24, 1951

R. L. Furniss, Entomologist, Portland Laboratory

Report - Height of Broods as a Factor Affecting the Treatment of Standing Lodgepole Pine Trees Infested by the Mountain Pine Beetle

This report by Johnson is of current interest to us because of an outbreak of the mountain pine beetle in lodgepole pine in central Oregon. It is probable that control of the outbreak will be effected through utilization rather then by direct control measures; however, it is helpful to have the latest information on direct control in case such measures have to be used.

Johnson's findings, plus recent data obtained by the Fort Collins Station on the effective height of spraying, would cause us to hesitate before undertaking a spraying-standing project on the Deschutes. While the infested heights on the Deschutes are not as great as Johnson shows for the Kootenai, many are greater than the effective heights of spraying, as reported from Fort Collins. The problem of whether to spray or not to spray seems to boil down to the question of how much untreated brood it is safe to leave. Is the 90 percent level of control mentioned for the Targhee-Teton control project now considered to be the acceptable standard? If so, I worry a little about the days on the Wasatch when a few square inches of lightly sprayed bark was cause for concern.

We have been thinking about hazard rating the lodgepole pine stands of the Deschutes and Klamath basins. Of course there isn't much to go on but certainly tree size and maturity, and perhaps stand structure and density have a bearing on the subject. Extent of stands of the older age classes and proximity to current infestations are other factors to consider. Perhaps you can suggest others. What we have in mind is a fairly broad classification of the lodgepole to be used as a guide in scheduling logging operations. Naturally the classification will be subject to change but it will be something to work from and improve upon.

This may seem far from the subject of brood heights, but there may be a connection. We hope to do much of the hazard rating from aerial photographs with appropriate ground checking. It should be possible to determine tree heights and sizes with reasonable accuracy. Such information should materially simplify the ground work necessary in deciding for or against the spraying-standing method on a given area.

cc: J. A. Beal
Berkeley
Ft. Collins
Ogden

RLFurniss:AH

RLF/mm1as:AH

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Dated by RLF

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PORTLAND, OREGON

Forest Insect Laboratory
Coeur d'Alene, Idaho

May 18, 1951

To: J. A. Beal, In Charge, Forest Insect Investigations

From: James C. Evenden, Box 630, Coeur d'Alene, Idaho

Subject: Mountain Pine Beetle Control - Standing Trees

I am enclosing a copy of an analysis by Mr. Johnson, of the problem of treating standing beetle infested lodgepole pine with penetrating sprays. This paper shows that this effective and economic technique of treatment cannot be adopted as a standard procedure. Its use is definitely limited to the height of infestation and to the height to which the spray can be properly applied.

Mr. Johnson points out that determining the height of infestation is a most difficult task, in fact I do not know of an infallible rule. This was recogni,ed at the time treating standing was first attempted. To meet the problem at that time, all trees that could not be treated to a 6-5 inch top diameter were felled for subsequent treatment. Some indices were adopted that helped to determine the height of infestation, but these were not beyond question. Trees with but few pitch tubes (so called blind attacks) and sapwood blued on all four sides, were expected to be infested to a maximum height. Other trees with numerous large pitch tubes, and blue stain on not more than three sides, were expected to show a short infested length. Although these were sound general rules, they were relative only.

At the start of the Targhee-Teton control project all trees were felled for treatment, as previous projects had shown that this procedure was as economical as the felling of some method. Woods labor was most scarce, and the felling of trees proved to be a very expensive and dangerous task. The following season, with better spraying equipment, to make available funds kill as many beetles as possible, all trees were treated standing. This action was based upon studies of infestation heights previously made in the Greys River Drainage which was a part of the project area. Although it was realized that a portion of the broods above the 35 foot level were left untreated, this procedure seemed to work fairly well on the Targhee-Teton project.

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Mr. Johnson points out that determining the height of infestation is a most difficult task, in fact I do not know of an infallible rule. This was recognized at the time treating standing was first attempted. To meet the problem at that time, all trees that could not be treated to a 6-8 inch top diameter were failed for subsequent treatment. Some indices were adopted that helped in determine the height of infestation, but these were not beyond question. Trees with but few pitch tubes (so called blind attacks) and sprayed blind on all four sides, were expected to be infested to a certain height. Other trees with numerous large pitch tubes, and blue stain on not more than three sides, were expected to show a short infested length. Although these were sound general rules, they were relative only.

At the start of the Targhee-Teton control project all trees were failed for treatment, as previous projects had shown that this procedure was as economical as the felling of some method. Woods labor was most scarce, and the felling of trees proved to be a very expensive and dangerous task. The following season, with better spraying equipment, to make available funds still as many beetles as possible, all trees were treated standing. This action was based upon studies of infestation heights previously made in the Grays River Drainage which was a part of the project area. Although it was realized that a portion of the brood above the 75 foot level were left untreated, this procedure seemed to work fairly well on the Targhee-Teton project.

2-J.A.Beal-5/16/51

Mr. Johnson has shown that with taller trees, the treatment of standing trees cannot be expected to give the desired result. Further control projects must recognize this fact, and when the percentage of tall trees is sufficient, the method must be abandoned in favor of felling. Mr. Johnson's analysis of this matter has crystalized our thinking in regard to this question of treating techniques.

cc: Regional Forester
Director, M.R.M.F.&R.E.S.
Fort Collins
Ogden
Portland ✓
Berkeley
Eastern Labs.

HEIGHT OF BROODS AS A FACTOR AFFECTING THE TREATMENT OF STANDING LODGEPOLE PINE TREES INFESTED BY THE MOUNTAIN PINE BEETLE

By Philip C. Johnson, Entomologist

The treatment of standing infested lodgepole pine trees as a means of controlling outbreaks of the mountain pine beetle, Dendroctonus monticolae Hopk., has gained favor since its inception on the Targhee-Teton Insect Control Project in Wyoming several years ago. The treatment consists of the spraying of bark penetrating insecticides on the boles of standing infested trees. Where the method can be used, it has been found to be much cheaper than other forms of treatment commonly used.

The method was evolved after (1) insecticides had been found that could penetrate the bark of lodgepole pine in small quantities and kill the beetle broods in the cambium, (2) studies had shown that the broods were commonly found from the ground level to heights on the bole which, in many instances, could be reached by insecticides sprayed from the ground, and (3) equipment had been designed and manufactured that could spray the insecticides sufficiently high enough to cover the infested portions of the boles of the standing trees. To date the treatment has been confined to the control of mountain pine beetle outbreaks in lodgepole pine.

The experience gained from several control projects using the "spraying standing" method of treatment has pointed out the need of further information on the heights reached by the beetle broods in the boles of infested trees. In one instance, the success of an entire project was jeopardized by insufficient information of this nature. It is the purpose here to discuss briefly the importance of brood height information when considering this method of treating, how it might be obtained, and how it can be used in control planning.

HEIGHT OF BEETLE BROODS IN THE BOLES

Certain factors have influenced the success of the spraying standing control method as it has been applied on several recent control projects. One of the most important of these obviously is the dispersal of the broods beneath the bark of the infested trees. Data taken from two projects -- the 1948-50 Targhee-Teton Insect Control Project in Idaho

and Wyoming[1] and the 1950 Boulder Creek Insect Control Project in Montana[2] -- indicate that mountain pine beetle broods are fairly consistent in occupying the lower portion of the bole. While broods in most trees extend down to the root crown level their upper limit is somewhat variable.

In the opinion of Messrs. Tom T. Terrell and Archie L. Gibson of the laboratory staff, the height to which mountain pine beetle broods may be found appears to depend upon bark thickness and upon the size of the population in relation to the available host material. The beetles apparently do not often attack where the bark thickness is less than the body height of the adult beetles. This, in effect, precludes the finding of beetle broods in boles less than 4 or 6 inches in diameter because of the thin bark normally encountered in them.

During epidemics when the beetle populations are heavy the boles of the infested trees conceivably may be infested from the ground to as high as these top bole diameters. The 4- to 6-inch minimum top diameters naturally will often be found at different heights on different trees. If the form factor is assumed to be consistent for lodgepole pine trees of different diameters and heights, then it follows that the heights of the minimum top diameters will vary according to the diameters (d.b.h.) of the trees. However, studies conducted in 1931 on the Wyoming (now Bridger) National Forest, Wyoming[3], indicated that the upper limits of the infested boles of lodgepole pine trees attacked by the mountain pine beetle do not consistently reach the minimum top bole diameters, but that they vary within the same diameter class as shown in Figure 1. This figure also shows that the same phenomenon occurred in mountain pine beetle-attacked trees measured on the Kootenai National Forest, Montana, in 1950[4]. In spite of this variation there is an indicated relationship

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1/ Targhee, Teton, Bridger, and Caribou national forests Idaho and Wyoming; Grand Teton National Park and Jackson Hole National Monument, Wyoming.

2/ Kootenai National Forest, Montana.

3/ Evenden, James C. Burning-standing method of bark beetle control. Report of the Forest Insect Laboratory, Bureau of Entomology, Coeur d'-Alene, Idaho. April 4, 1932.

4/ Data furnished by Mr. Merrill D. Oakes, Project officer, Kootenai National Forest, Libby, Montana, February 1951.

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During epidemics when the beetle populations are heavy the boles of the infested trees conceivably may be infested from the ground to as high as these top bole diameters. The 5- to 6-inch minimum top diameters naturally will often be found at different heights on different trees. If the form factor is assumed to be consistent for lodgepole pine trees of different diameters and heights, then it follows that the heights of the minimum top diameters will vary according to the diameters (d.b.h.) of the trees. However, studies conducted in 1951 on the Wyoming (now Bridger) National Forest, Wyoming[3], indicated that the upper limits of the infested boles of lodgepole pine trees attacked by the mountain pine beetle do not consistently reach the minimum top bole diameters, but that they vary within the same diameter class as shown in Figure 1. This figure also shows that the same phenomenon occurred in mountain pine beetle-attacked trees measured on the Kootenai National Forest, Montana, in 1950[4]. In spite of this variation there is an indicated relationship

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3/ Wyeden, James G. Barring-stunding method of bark beetle control. Report of the Forest Insect Laboratory, Bureau of Entomology, Coeur d'Alene, Idaho. April 5, 1952.

4/ Data furnished by Mr. Merrill D. Yates, Project officer, Kootenai National Forest, Libby, Montana, February 1951.

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between the average and maximum heights of infested boles in different tree diameter classes and in lodgepole pine stands of different site indexes (figure 2).

DISCUSSION

There are a number of factors to be considered in the treatment of standing mountain pine beetle-infested lodgepole pine trees -- the efficiency of the spraying equipment; the availability of the insecticide; the mixing, storage, and transportation of the insecticide; wind conditions during treatment; and the hiring of capable spray men; to mention a few. These may or may not influence the choice to treat an infestation by spraying the boles of standing beetle-attacked trees after it has been determined that this technique is applicable. To determine whether the technique itself is applicable, it is necessary to obtain the following information about each stand considered for treatment:

1. The maximum height to which the infested boles can be sprayed with the spraying equipment available.

2. The height of the broods in trees of different sizes, usually the average and maximum infested heights in each 2-inch diameter (d.b.h.) class.

3. The relation of tree height to diameter class.

4. A stand table showing the number of trees in each diameter class.

The sprayable height usually is predetermined by the spraying equipment available. The present equipment developed at this laboratory combines a commercial stirrup pump, telescopic spray rod, and a specially constructed spray nozzle to throw the spray solutions or emulsions to a height of 35 feet above the ground. This height probably can be raised without sacrificing the portability of the equipment by using more of the pump's rated pressure capacity and by increasing the spray rod length and nozzle orifice. Spraying insecticides to greater heights may require heavier equipment, greater spraying effort, and may cause some waste of spray mixture through the inability of the sprayman to control the stream at the greater heights.

The infested heights in trees of different sizes can be determined fairly easily in a given stand by making bole analyses of selected, felled, infested trees. At the moment, this would seem to be a prerequisite where the spraying standing method is contemplated. From similar sampling in stands representing a number of varying site and infestation conditions, it might be possible in time to develop a simple rule-of-thumb method to indicate the average or maximum infested bole height for trees of different diameters in any stand. The decision then as to

whether the standing spraying method was applicable in a specific stand would depend merely upon a knowledge of its site index, or indexes, and of the number of infested trees in each diameter class.

This would represent a utopian condition that might be difficult to achieve, because there are indications that the heights of the beetle broods in the boles of infested lodgepole pine trees vary somewhat from year to year even in trees of the same diameter. This may be due to changes in the magnitude of the mountain pine beetle populations as the infestation in a given stand increases or slackens in intensity.

The effectiveness of this method of beetle control is naturally greatest where the infested heights of the treated trees is equal to or below the maximum height to which the boles can be sprayed. Assuming that the spraying job was fully effective, then 100 percent of the broods would be treated. The effectiveness of the method declines as the infested heights of the boles exceed the maximum height of the spray. In this situation, the control planners must know how much of the brood will be left untreated and whether the leaving of this amount of untreated brood will nullify the benefits of the control program.

It is conceivable that that portion of the brood above the sprayable limit may sometimes be left untreated with no harmful results. Incompleted work of the late Dr. Charles D. Bedard, formerly of this laboratory, indicated relatively high concentrations of mountain pine beetle parasites at the upper bole levels in western white pine. His work indicated that the mountain pine beetle broods in the upper boles should purposely be left untreated by any artificial means so that the parasites would not be destroyed. The parasites would not only destroy the pine beetle broods left untreated in the upper boles, but they would in all probability increase in number and help to hold post-control pine beetle broods in check in the treated area.

Bean[1/] , however, found that this was not the case in lodgepole pine. He reported that 69 percent of the mountain pine beetle parasite population was in the basal one-third of the infested bole, 27 percent was in the middle one-third, and 4 percent in the top one-third. Thus, most of the parasites would be destroyed by the standing spraying treatment of infested lodgepole pine trees. Any parasites surviving above the sprayed portion of the boles might be too few in number in most instances to effectively destroy the surviving pine beetle broods in the same bole region.

1/ Bean, James L. The effects of control measures on the mountain pine beetle (Dendroctonus monticolae Hopkins) in lodgepole pine, Teton National Forest, Jackson, Wyoming. Report of the Forest Insect Laboratory, Bureau of Entomology and Plant Quarantine, New Haven, Connecticut. April 1949.

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Yet it has been shown on the Targhee-Teton Insect Control Project that good control resulted from treating 90 percent of the pine beetle broods and leaving an estimated 10 percent untreated above the maximum spraying height. The estimate of the percentage of the broods treated was arrived at by first determining the average height of infestation for each diameter class (Table 1), and then, from a stand

Table 1. Height of mountain pine beetle infestations in boles of standing lodgepole pine trees, by diameter classes. Bridger National Forest, Wyoming. 1931.1/

Diameter Class, d.b.h. (inches)	Height Of Infested Bole (feet)		Percentage Of Untreated Infested Bole Height Above 35 Feet	Percentage Of Untreated Beetle Broods Above 35 Feet
	Average	Maximum		
6	17	26	0	0
8	20	34	0	0
10	23	40	12.5	2.0
12	26	45	22.0	5.0
14 2/	29	48	27.0	8.0
16	31	50	29.5	9.0
18	32	51	30.5	9.5
20	34	51	31.0	10.0

1/ Data taken from Wyoming (now Bridger) National Forest, Wyoming, 1931, and included in a laboratory report by James C. Evenden, April 4, 1932, entitled "Burning-standing method of barkbeetle control"; and from Bitterroot National Forest, Montana in a report by Archie L. Gibson, April 1926, entitled "Progress report of study of epidemic of Dendroctonus Monticolae Hopk. in lodgepole pine and yellow pine, Bitterroot National Forest, 1926."

2/ Modal diameter of the stand.

table, by determining the number of trees in each class. From this, it was possible to estimate that 90 percent of the beetle broods could be treated and that 10 percent 35 feet or more above the ground could not be reached by the spray.

This situation poses a neat problem, for, in order to spray all infested trees high enough to insure the insecticide reaching, say, 90 percent of the beetle broods in the control area, many trees will necessarily be sprayed above the infested portion of the boles. If the heights of the infestation in trees of the same diameter class are erratic, it is reasonable to expect that a considerable volume of insecticide will be used ineffectually to treat uninfested portions of the boles. It is the job of the control planners to estimate what part of the total insecticide volume might thus be used. When it is considerable its cost, together with the cost of mixing, storing, and transporting it into the forest, could influence the net treating cost per tree appreciably.

The present meager knowledge of the heights of mountain pine beetle broods in infested lodgepole pine trees and its importance in control planning justifies further study. The soundness of the standing spraying method must be proven by more adequate knowledge of brood heights in trees of different sizes, in stands of varying site quality, and under changing infestation conditions. This can be done by purposely felling infested trees for brood height measurements or by obtaining these measurements from infested trees felled for treatment by other methods.

Another study might use this information to develop the previously-mentioned rule-of-thumb to apply to infested stands as a measure of their adaptability to the spraying standing method of control. The components of such a rule might include the relationship between brood heights and the diameter and total height of the infested trees and possible correction factors for such things as stand density; rising, peak, and declining infestation trends; and bark beetle population density per unit of basal bark surface.

Any rule developed for this purpose, whether simple or complex, must transpose into its formula certain basic measurements of the stand to be treated. These measurements in all probability would be obtained by the field crews making the reconnaissance or appraisal surveys of the infestation with little extra effort. Because of the limitations of the spraying standing method this procedure seems to be an inescapable prerequisite to this type of treatment.

Studies of this kind could well be made for other bark beetle and host species where possibilities exist for destroying the broods by spraying the infested trees standing. Until these studies are made the capabilities of this method of treating trees will never be fully known and its effectiveness on a given control job cannot be predetermined except by a considerable amount of field sampling of these same infestation and stand factors.

FIG. 1

VARIATION IN HEIGHTS OF BOLE INFESTATIONS WITHIN DIAMETER CLASSES

MOUNTAIN PINE BEETLE IN LODGEPOLE PINE

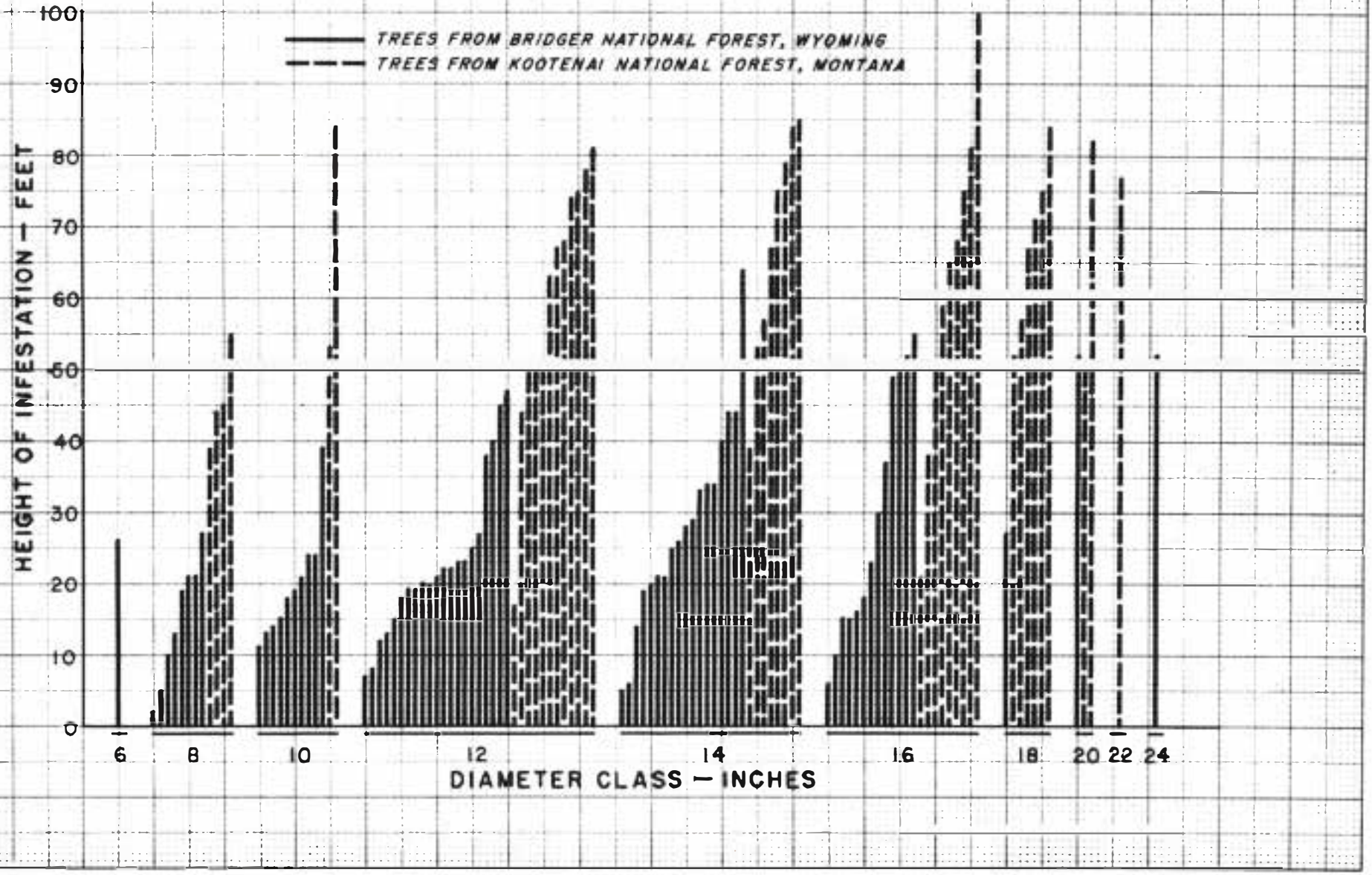
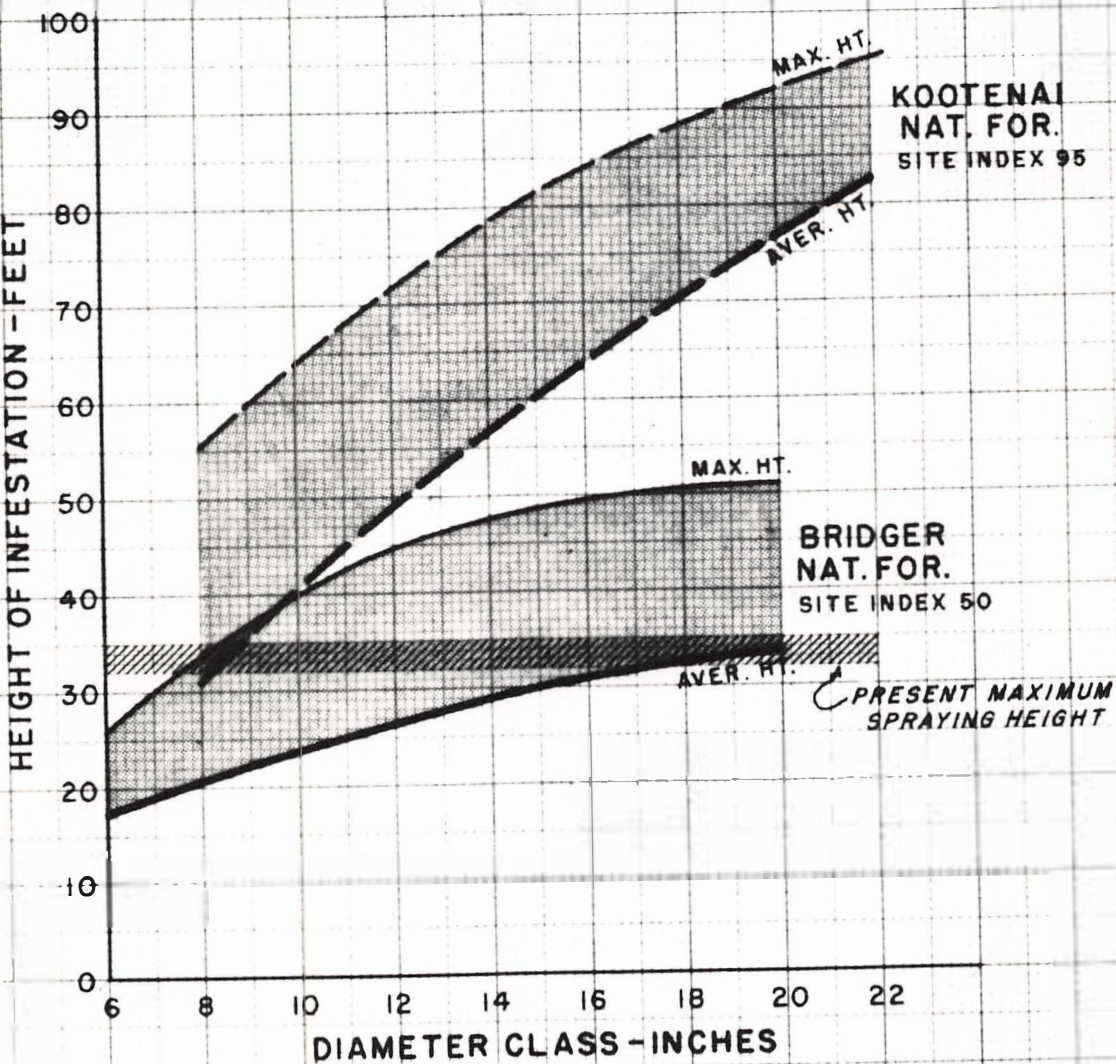


FIG. 2

COMPARATIVE HEIGHTS OF INFESTED BOLES

MOUNTAIN PINE BEETLE IN LODGEPOLE PINE



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Attractiveness of Lightning-Struck Ponderosa Pine Trees to *Dendroctonus brevicomis* (Coleoptera: Scolytidae)[1]

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Frequent summer thunderstorms in the northern Rocky Mountains are characterized by numerous discharges of lightning between clouds and between clouds and the earth. About one-third of all the discharges contact the earth in mountainous country, usually on exposed, rocky ridgetops. Not uncommonly these discharges strike either living trees, the crowns of which project above the general canopy of dense forests, or isolated trees in more open stands. This paper reports observations made by the author in connection with a recent study in Montana of mortality factors in old-growth ponderosa pine forests. This study of mortality factors showed lightning to be directly responsible for killing 3.8% of all pine trees killed, or 7.3% of the commercial board-foot volume of all trees killed by all rapid-killing factors measured.

Occasionally, a tree literally exploded when struck by lightning. However, most of the struck pine trees examined in this study appeared to be uninjured except for a single 2- to 4-inch-wide streak of exposed cambium that extended along the bole parallel to the grain of the sapwood. Survival of these trees indicated that lightning strikes are not necessarily lethal to mature ponderosa pine trees.

About 80% of all mature pine trees struck by lightning were attacked and killed by the western pine beetle, *Dendroctonus brevicomis* LeConte. There were indications that most of these trees were attacked in the same season they were struck by lightning. The breeding potential of the beetle in lightning-struck pine trees was estimated to be considerably more than that in the living ponderosa pine trees that they normally attack. This estimate was derived from (1) the number of pitch tubes, denoting beetle entrance holes, on the surface of the bole bark; (2) the abundance of beetle broods beneath and within the bark; and (3) the number of beetle emergence holes in the bole bark.

The mean number of emergence holes in lightning-struck trees was estimated from random measurements to be from 150 to 200/ft² of bole bark. In contrast, Keen (1960) reported a mean of 63 holes/ft² in normal host trees. The maximum number of emergence holes reported by Keen was 340/ft² of bark, whereas the maximum number of holes in lightning-struck trees in Montana was 460/ft². On the basis of 1.46 new adult beetles exiting from each emergence hole, as determined by studies in California, it is evident that lightning-struck trees are a potent source of further infestation of the pine stands in which they occur.

Why lightning-struck ponderosa pine trees should especially attract new adult beetles of *D. brevicomis* has not been determined. A possible explanation of this biotic relationship may be found in reports of some of the pioneer studies of bark beetle attractants. In his exploratory studies on the chemoattractants of *D. brevicomis*, Mirov[2] demonstrated that fermented phloem strongly attracts this beetle. Gordon[3] later used a laboratory olfactometer to determine the highly positive chemotropic response of the beetle to volatile odors of fermented phloem.

Palladin (1914) pointed out that a form of alcoholic fermentation of the phloem of living trees can result from carbohydrate decomposition in the process of anaerobic, or intramolecular, respiration. This physiologic function may be found in certain slow-growing trees, and it may be induced or accelerated by mechanical wounding of trees. Furthermore, Palladin states, mechanical wounds provide entry to micro-organisms that can cause fermentation of phloem tissue.

From these studies, it may be hypothesized that fermentation of the phloem, whether by anaerobic respiration or from external micro-organisms, could be a product of the wounding of ponderosa pine trees by lightning. It is possible also that the volatile odors of this material emanate from these trees in sufficient abundance to attract a significant proportion of newly emerged adults of *D. brevicomis* from immediate surrounding areas within host forests.

For several reasons, the attractiveness of lightning-struck trees to *D. brevicomis* should seriously concern foresters who manage old-growth ponderosa pine forests:

1. The attractiveness to the beetle is usually induced rather than direct, and it results in the killing of trees that might not otherwise be attacked by this pest.
2. Ponderosa pine trees struck by lightning, when infested by beetles, often produce larger broods than normal pine trees.
3. The lightning-struck trees in old-growth ponderosa pine stands usually are the largest and contain the greatest commercial board-foot volume. The lightning-struck trees observed in this Montana study had a mean volume of 2,090 board feet, whereas trees normally attacked by *D. brevicomis* have a mean of 970 board feet, and all pine trees in the stands have a mean of 859 board feet. The death of lightning-struck trees from beetle attacks therefore represents a greater proportionate per-tree loss than that from other tree mortality factors.

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[1] Accepted for publication October 4, 1965.

[2] N. T. Mirov. 1928. A preliminary study of attraction with the western pine beetle, *Dendroctonus brevicomis* Lec. Unpub. rep., Bur. Entomol., USDA, Berkeley, Calif. December 5. 32 p.

[3] A. Gordon. 1932. Chemotropic tests of *Dendroctonus brevicomis*. Unpub. rep., Bur. Entomol., USDA, Berkeley, Calif. Undated. 4 p.

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